Gas emissions from three persistent lava lakes

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1. Introduction

Lava lakes are a rare and spectacular phenomenon of nature. They represent the exposed upper part of a magma conduit and, as such, provide a unique window into magmatic processes occurring beneath a volcano. Here we compare high temporal resolution Fourier transform infrared (FTIR) spectroscopic measurements of the chemical composition of gas emitted from three volcanoes, all of which are host to persistently active lava lakes: Erta ‘Ale (Ethiopia), Nyiragongo (Democratic Republic of the Congo) and Erebus (Antarctica). Measured species include H_2O, CO_2, SO_2, CO, HCl, HF and OCS.

1.1 Erta ‘Ale

Erta ‘Ale (13.60ºN, 40.67ºE; alt. 613 m) is a basaltic volcano[1] located in the Danakil depression of Ethiopia. The volcano is renowned for its long-lived, persistently convecting and degassing, lava lake(s), one in the northern lobe of the summit caldera (currently not visible) and the other in the central lobe (~ 30 m in diameter, Figure 1a).

1.2 Nyiragongo

Nyiragongo volcano (1.52ºS, 29.25ºE; alt. 3469 m), in the north eastern Democratic Republic of the Congo, forms part of the Virunga volcanic chain that lies on the western branch of the East African Rift System. It erupts rare alkaline and strongly silica-undersaturated leucite-, melilite- and nepheline-bearing basanitic lavas[2]. It currently hosts a vigorously convecting and persistently degassing lava lake, 250-300 m in diameter (Figure 1b).

1.3 Erebus

Mt. Erebus (77.53ºS, 167.17ºE; alt. 3794 m) is situated on Ross Island, Antarctica. It is host to a convecting, and persistently degassing, lake of anorthoclase phonolite magma[3], ~40 m in diameter (Figure 1c). Regular updates on volcanic activity at Erebus are available at the Mt. Erebus volcano observatory webpage; http://erebus.nmt.edu/.

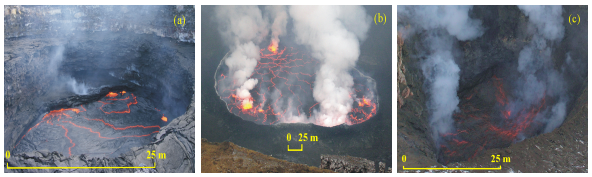

Figure 1: Lava lakes at **(a)** Erta ‘Ale (diameter ~30 m) photographed from the south eastern crater rim of the central pit crater, 15 October 2005 and **(b)** Nyiragongo (diameter 250 - 300 m) photographed from the south eastern crater rim of the summit crater, 19 June 2007. **(c)** Erebus (diameter ~40 m) photographed from Shackleton’s Cairn on the northern rim of the summit crater, 4 December 2006. The scale bars each represent an approximate 25 m distance on the surface of the lava lakes.

2. Methodology

Plume composition measurements were made using a portable MIDAC Corporation FTIR spectrometer equipped with an interchangeable liquid nitrogen cooled MCT or InSb detector with sensitivities between 600 and 5000 cm^{-1} and 1800 and 6000 cm^{-1} respectively. At Erta ‘Ale 288 spectra were collected on 15 October 2005. At Nyiragongo a total of 3500 spectra were collected in May/June 2005, January 2006 and June 2007. At Erebus ~360,000 spectra were collected in December 2004, 2005, 2006 and 2007. A detailed description of the methodology can be found in references **4, 5** and **6**. Here we only summarise the essentials.

Absorption spectra were collected at 0.5 cm^{-1} resolution using the lava lakes as a source of infrared radiation. To retrieve column amounts (in units of molecules cm^{-2}) of infrared-active volcanic gas species present in the path between the source of IR radiation and the detector, infrared spectra were first simulated in specified frequency microwindows via a radiative transfer forward model using line parameter data from the HITRAN database[7]. These simulated spectra were then fitted to the measured spectra using an optimal estimation algorithm and a non-linear least squares fitting procedure. Further details on the retrieval procedure are given in reference **8**.

3. Results

From each measured spectrum we retrieved column amounts of H_2O, CO_2, SO_2, CO, HCl, HF and OCS. We then calculated molar X/Y gas ratios from the gradient of linear regression lines fitted to plots of species X vs. species Y (Figure 2). Assuming that our measured gas species made up 100 % of the plume, we then calculated average molar proportions of these species (Table 1).

3. Results cont.

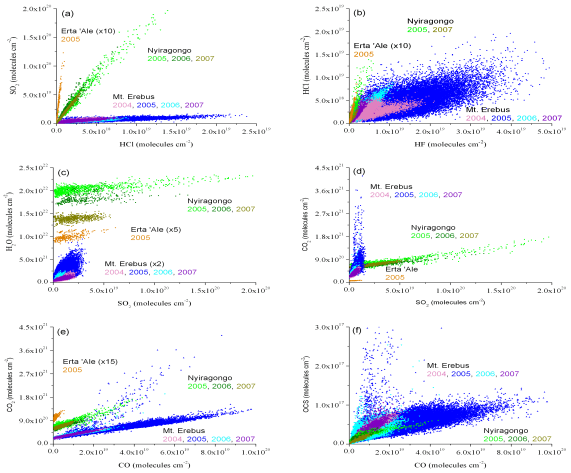

Figure 2: All FTIR spectroscopic data acquired at Erta ‘Ale, Nyiragongo and Erebus volcanoes. In **(d)**, **(e)** and **(f)** anomalously high column amounts of OCS and CO_2 are observed in the Erebus 2005 dataset. These signatures are observed during strombolian explosions[6]. In **(f)** column amounts of OCS at Erebus in 2005 reached 1.8×10^{18} molecules cm^{-2} but these data have been omitted in order to show passive emissions in more detail.

Gas	Erta ‘Ale central lava lake (mol %)	Nyiragongo (mol %)	Erebus (mol %)
H_2O	93.58	70.36	62.15
CO_2	3.66	23.82	32.53
SO_2	2.47	4.62	1.01
CO	0.06	0.87	2.50
HCl	0.19	0.26	0.70
HF	0.04	0.11	1.11
OCS	-	0.0023	0.0080

Table 1: Mean gas composition measured at Erta ‘Ale central crater (Oct 2005), Nyiragongo (May/Jun 2005, Jan 2006 and Jun 2007) and Erebus (December 2004, 2005, 2006 and 2007).

4. Conclusions

We suggest the main differences in the gas compositions can be reconciled in terms of the magmas that are erupted. Nyiragongo and Erebus are alkalic volcanoes and hence associated with low degrees of partial melting and high concentrations of CO_2, SO_2 and the halogens (HCl and HF)[9]. The most similar gas compositions to Nyiragongo and Erebus has been reported at Etna (Sicily)[10], which is renowned for its alkaline magma. At Erta ‘Ale the gas plume is considerably more water-rich (Table 1), consistent with the tholeiitic basalts that are erupted. The most similar reported gas compositions to Erta ‘Ale are from Surtsey (Iceland: H_2O/CO_2 ~30, CO_2/SO_2 ~1.8)[11] and Ardoukoba (~300 km SE of Erta ‘Ale: H_2O/CO_2 ~21, CO_2/SO_2 ~0.3)[11]. Both of these volcanoes are located in regions of tectonic extension, and erupt similar lavas to Erta ‘Ale.

Whilst the proportions of H_2O and CO_2 at Nyiragongo and Erebus are comparable, proportions of SO_2, HCl and HF differ significantly (Table 1). At Erebus, the phonolites represent a ~25% residual melt resulting from fractionation of basanite (through phonotephrite and tephriphonolite)[3]. Analyses of melt inclusions indicate high S content of the basanites, supposed to be the parental melts feeding Erebus (~2500 ppm), but the amount of S decreases as the magma evolves. The evolved phonolite magmas that are currently erupted at Erebus[3] contain less than 500 ppm sulphur[12]. Emissions of S-bearing gas species (SO_2 and H_2S) at Erebus are low[13] so we suggest high pressure fractionation and precipitation of S in sulphide minerals as an explanation for the loss of S during fractionation. At Nyiragongo, a petrogenetic model for the volcanics has been suggested that invokes low-pressure fractionation[14]. This favours exsolution of S rather than locking it up in mineral phases, and is consistent with the higher S content in the Nyiragongo gas emissions. In contrast to the data on S, the concentrations of Cl and F in melt inclusions from Erebus increase with increasing degrees of magma fractionation[12]. This suggests these elements are concentrated in the melt during fractionation before partitioning into the gas phase (along with some incorporation into apatite). Magmas at Nyiragongo are much less evolved than those found at Erebus thereby providing a possible explanation for the difference in the halogen emissions between the two volcanoes.

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